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In Situ Vitrification Application to Buried Waste: Final Report of Intermediate Field Tests at Idaho National Engineering Laboratory

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IN SITU VITRIFICATION APPLICATION TO BURIED WASTE: FINAL REPORT OF INTERMEDIATE FIELD TESTS AT IDAHO NATIONAL ENGINEERING LABORATORY

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IDAHO NATIONAL ENGINEERING LABORATORY
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August 1991

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ABSTRACT

This report describes two in situ vitrification field tests conducted on simulated buried waste pits during June and July 1990 at the Idaho National Engineering Laboratory. In situ vitrification, an emerging technology for in-place conversion of contaminated soils into a durable glass and crystalline waste form, is being investigated as a potential remediation technology for buried waste. The overall objective of the two tests was to assess the general suitability of the process to remediate waste structures representative of buried waste found at Idaho National Engineering Laboratory. In particular, these tests, as part of a treatability study, were designed to provide essential information on the field performance of the process under conditions of significant combustible and metal wastes and to test a newly developed electrode feed technology. The tests were successfully completed, and the electrode feed technology successfully processed the high metal content waste. Test results indicate the process is a feasible technology for application to buried waste.

SUMMARY

During June and July 1990 two in situ vitrification (ISV) field tests were conducted at Idaho National Engineering Laboratory (INEL) to investigate the application of ISV to buried waste. The Intermediate Field Tests were a cooperative effort between INEL and Battelle, Pacific Northwest Laboratory (PNL) using PNL intermediate-scale processing equipment.

The Intermediate Field Tests were conducted as part of a treatability study investigating ISV as a potential remediation technology for use at the Subsurface Disposal Area (SDA) of INEL. The U.S. Department of Energy has identified the need to remediate waste disposed between 1954 and 1970 at the SDA. Concerns over the human health and environmental effects of the wastes disposed at the SDA have arisen due to the discovery of various contaminants, notably solvents, in groundwater underlying the site. In addition, organic contaminants and radionuclides have been detected in sedimentary interbeds and perched groundwater beneath the SDA, indicating migration away from the disposal area. As a result of these discoveries and other waste disposal activities, INEL was included in November 1989 on the U.S. Environmental Protection Agency National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act. This listing has led to the need for the remedial investigation/feasibility study (RI/FS) currently being conducted for the SDA. These tests were conducted as part of the RI/FS process.

The objectives of these field tests were the following:

- verify the operational suitability of the electrode feeding system
- verify acceptable vitrification in a region containing buried waste similar to that expected at the INEL SDA
- verify acceptable vitrification of a representative buried waste composition layer with minimum soil content

- verify acceptable vitrification of a buried waste layer with high metal content, approximately 11 wt% metal

- assess the potential for radionuclide transport during the vitrification of buried waste by using nonradioactive tracer materials such as dysprosium oxide, terbium oxide, and ytterbium oxide

- obtain engineering and scientific data necessary to assess the engineering capability of the ISV system, the safety of the process streams, and the suitability of the process as a remedial method for application to INEL buried waste.

Two test pits were constructed near the Water Reactor Research Test Facility at INEL. These pits contained simulated waste with no hazardous or radioactive material. Test Pit 1 was designed to simulate a waste region of randomly disposed drums and boxes intermixed with fill dirt. Test Pit 2 was designed to simulate a region of stacked drums and a stacked box region containing high metal content waste. The materials contained in the drums and boxes were similar to waste types contained within the SDA buried waste.

The first Intermediate Field Test started on June 12, 1990 and continued until June 15, reaching the depth of 2.4 m (8 ft). This test was more dynamic than previous ISV tests conducted by PNL. A series of pressure and temperature transient spikes occurred within the off-gas hood as cans of buried combustible material were encountered. Electrical imbalances occurred in the power transformer due to an unusually small volume of molten glass and the lack of sufficient electrode control due to electrode sticking. The small volume of molten glass resulted from the greater percentage of void space in regions of buried waste relative to the normally occurring void percentage in soil. The smaller amounts of molten glass magnify the effects of transients on the power supply system. The insufficient electrode control resulted from the electrode coating sticking to the cold cap formed on top of the melt, thus, reducing the effectiveness of the electrode feed system. The test was terminated when the advancing molten glass melted away from one of the electrodes resulting in loss of power to the melt.

Based on the experiences of Test 1, several changes were instituted prior to initiation of Test 2. These changes included additional overburden soil placed on top of the waste layer to provide a larger volume of molten glass, noncoated electrodes to reduce sticking, additional operational control of electrodes using the electrode feed system to reduce the effects of transients on the power system, and an additional backup blower added to the air inlet side of the hood to reduce the severity of hood pressure transients.

The second Intermediate Field Test was conducted July 12-14, 1990. During this test the melt proceeded through the test pit to a depth of approximately 3.9 m (10.8 ft). The melt penetrated both the stacked can region and the stacked box region of high metal content waste. Hood pressure transients were much reduced relative to Test 1 due to the increased amount of overburden placed over the waste, the increased control over electrode insertion and melt rate, and the more uniform heating of the stacked can region that was observed. Electrical imbalances were also reduced relative to Test 1 due to the additional operational control of the electrode feed system and power transformer.

Upon completion of Test 2, the two ISV blocks were allowed to cool prior to excavation on September 10, 1990. A careful and systematic excavation of the ISV processed pits was conducted in order to obtain physical descriptions of the waste pit morphology, the processed waste, and the vitrified product. Additionally, samples were collected for chemical and physical analysis and durability testing. Cores were drilled into the waste form and metal that pooled in the bottom of each pit to obtain analytical samples.

The general shape of Test Pit 1 after ISV processing was a square shaft with rounded corners. The depth from ground surface to the uppermost glassy material in the pit bottom, as measured directly from ground level, was about 1.5 m (5 ft). Depth from ground surface to the monolith centered among the four electrodes, was found to be about 1.9 m (6.1 ft). The monolith was approximately oval and about 1.5 x 1.8 m (5 x 6 ft) with the long axis under diagonal electrodes (SW to NE). The thickness of the monolith was about 0.55 to 0.61 m (1.8 to 2.0 ft). The total amount of processed waste form recovered was 8267 kg (18,225 lb).

The general shape of the Test Pit 2 waste form was approximately rectangular with rounded corners. A significant amount of subsidence was observed in Test 2 with an approximate 60% reduction in volume as a result of processing. The depth from ground surface to the monolith upper surface ranges from 2.2 to 2.3 m (7.2 to 7.5 ft), with the monolith being 0.98 m (3.2 ft) in thickness. The maximum dimension of the monolith rectangle was 3.35 m (11 ft) and minimum was 2.90 m (9.5 ft). The weight of the monolith was 13,109 kg (28,900 lb), and the total amount of vitrified waste recovered from Test Pit 2 was 17,430 kg (38,425 lb). All waste within the melt volume was processed.

The product from both pits generally consisted of a black (with green tints) glassy material containing variable amounts of bubbles and crystalline material. The amount of bubbles varied with position in the pits. Although the crystalline materials found in the products from the two test pits were very similar, the megascopic appearance of the materials was somewhat different. Glass was the principle phase found within the monoliths. The outermost portion of the monolith, the most quickly cooled portion, was glassy with little devitrification (crystals). The Pit 1 waste form was smaller, cooled quicker, and so had little devitrification. Most of the material in the Test Pit 2 monolith was quite different in appearance. The Test Pit 2 monolith consisted of an outermost zone of black glass about 5.1 cm (2 in.) thick followed by a white to beige to lavender zone with a very fine crystal structure (aphanitic) region 5.1 to 10.2 cm (2 to 4 in.) thick that graded into a courser crystal structure (phaneritic) material. During cooling, devitrification occurred within the glass monolith producing a feather-like crystalline phase called augite. The mineral augite, a variety of clinopyroxene, is a calcium-magnesium-iron rich silicate. Augite is a common, naturally occurring pyroxene found in volcanic rocks, such as the basaltic rocks found at the INEL, which have compositions and cooling histories similar to the vitrified material in the Intermediate Field Tests reported here.

A series of tests were performed to determine the dissolution behavior of product samples. The IFT waste forms do not exhibit hazardous characteristics of TCLP toxicity. Based on MCC-1 leach testing data, the durability of the IFT waste form is comparable to naturally-occurring obsidian and granite, and 4 to 10 times more durable than typical high-level borosilicate nuclear waste glasses. Preliminary results from intrinsic rate constant measurements showed that the dissolution rates of the ISV samples range from 0.01 to 0.06 $g/(m^2 \cdot d)$ at 90°C and pH 7. These values are 10 to 100 times smaller than measured for a typical borosilicate nuclear waste glass. Devitrified samples from these tests showed a trend to be more durable in dissolution behavior than amorphous samples of equivalent bulk composition. Solids characterization of the ISV products showed that the ISV melts are chemically reducing, resulting in Fe^{2+}/Fe ratios >90%. Under equivalent closed-system conditions, as might occur during the slow migration of water through cracks in the solid mass, the reaction of the ISV glass with water reduces the redox potential to the lower stability limit of water. Under these conditions, several redox sensitive elements such as Se and Pu are expected to be sequestered in an alteration layer on the glass surface resulting in a smaller predicted release rate than calculated from the matrix dissolution rate alone.

As part of these tests, a tracer study was conducted during testing to provide qualitative assessment of the potential for radionuclide release during ISV processing of buried waste. During preparation of the test pits, rare-earth tracer elements were added to selected waste containers. The added tracers were oxides of dysprosium, terbium, and ytterbium (Dy_2O_3, Tb_4O_7, Yb_2O_3).

After testing, the amounts of tracers were measured in the vitrified product, in the smears of interior hood and off-gas piping surfaces, in the scrub solution, and in soil adjacent to the melt. Quantitative determination of tracer amounts was hampered by sampling and analysis uncertainties. Nevertheless, results indicated that the majority of each tracer was retained in the vitrified product as anticipated. The tracers concentrations were relatively homogenous throughout the glass and crystalline product. Order-of-magnitude estimates for amounts of tracer materials released into the off-gas system for Test 1 were several grams to several tens of grams. This corresponds to up to several percent of the amounts initially added to the pit.

The results of the tracer study suggest the need for further effort to estimate the potential for radionuclide release during ISV processing. Further data are needed to quantify the magnitude of element retention by the melt; however, the data suggest that during buried waste ISV processing the retention of rare-earth tracers in the melt may be less than values previously reported for plutonium retention during processing of contaminated soil. The more dynamic melt off-gassing processes observed in these tests may enhance element release from the melt. Extrapolation of tracer results into predictions of plutonium behavior is currently without empirical foundation under ISV conditions; this is an area needing further investigation, including both theoretical analysis of release mechanisms and additional experimental data.

Compared to previous ISV applications to contaminated soils conducted at other Department of Energy sites, ISV processing of buried waste at INEL resulted in a more dynamic process, especially with respect to melt off-gassing and electrical transients in the power system. Containment of off-gases within the hood may require a more robust hood and off-gas system than currently designed. An improved design for off-gas containment may also be required for other ISV applications capable of generating sudden gas releases, such as underground tanks. These engineering considerations do not imply limitations in the fundamental ISV process.

Analytical modeling of the hood off-gassing transients was conducted in an attempt to improve understanding of physical mechanisms of off-gassing. These efforts were of limited value because data collection was not sufficient to validate assumptions in the models used. However, based on the measurements and results of these tests, recommendations are made for future testing and data collection design to address off-gassing mechanisms.

Results from these tests indicate that the ability to add glass-forming materials during processing may be desirable for buried waste ISV. A significant volume reduction of the processed buried waste is attained; however, the resulting subsidence may result in uncovering adjacent waste. Potential hazards of posttest activities would be alleviated by adding sufficient material (soil) during processing to keep the waste from being uncovered. This additional material may also serve to reduce electrical instabilities by reducing the impact of events such as glass flow into adjacent containers in the melt. Additional material may also buffer off-gas release as suggested by a comparison of results from these two tests.

The successful completion of these tests indicates ISV is a feasible technology for application to buried waste. The process fully incorporated and dissolved simulated waste containers to produce a durable product. The electrode feed technology was successful in processing the high metal content waste. The technique developed for use of movable electrodes will be beneficial for other ISV applications.

Additional assessment of the ISV process for application to buried waste is being conducted at INEL using an integrated program of laboratory-testing, field-testing, and analytical modeling.

ACKNOWLEDGMENTS

The successful completion of the ISV Intermediate Field Tests resulted from the combined efforts of many people at several institutions. The authors gratefully acknowledge the support provided by staff members from PNL, INEL, and the Geosafe Corporation. Their support significantly contributed to the success of these tests.

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CONTENTS

FIGURES

TABLES

ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data Acquisition System
DF	decontamination factor
DIW	deionized water
DOE	Department of Energy
EFS	electrode feed system
EPA	Environmental Protection Agency
HEPA	High-efficiency particulate air
IC	ion chromatography
ICPAES	inductively coupled plasma, atomic emission spectrometry
IFT	Intermediate Field Test
INEL	Idaho National Engineering Laboratory
ISV	in situ vitrification
MRL	miminum reporting limit
NIST	National Institute of Standards and Technology
ORNL	Oak Ridge National Laboratory
PCT	Product Consistency Test
PD	Priority Data
PNL	Battelle, Pacific Northwest Laboratory
QC	quality control
REE	rare-earth element
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
RWMC	Radioactive Waste Management Complex

SDA	Subsurface Disposal Area
TAN	Test Area North
TCLP	Toxicity Characterization Leach Procedure
TRU	transuranic
WRRTF	Water Reactor Research Test Facility
WTDD	Waste Technology Development Department

IN SITU VITRIFICATION APPLICATION TO BURIED WASTE: FINAL REPORT OF INTERMEDIATE FIELD TESTS AT IDAHO NATIONAL ENGINEERING LABORATORY

1. INTRODUCTION

The U.S. Department of Energy (DOE) has identified the need to remediate waste disposed between 1954 and 1970 at the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC) at Idaho National Engineering Laboratory (INEL). The discovery of various contaminants, notably solvents, in groundwater underlying INEL has raised concerns over human health and environmental effects. In addition, organic contaminants and radionuclides have been detected in sedimentary interbeds and perched groundwater beneath the SDA, indicating migration away from the disposal area.[1] In November 1989, as a result of these discoveries and other waste disposal activities, INEL was placed on the U.S. Environmental Protection Agency (EPA) National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This listing has led to the need for the remedial investigation/feasibility study (RI/FS) currently being conducted at the SDA.

As part of the RI/FS, EG&G Idaho Waste Technology Development Department is conducting a treatability investigation of ISV as a remedial technology for use at the SDA. In situ vitrification (ISV) represents a promising technology for application to buried wastes. The technology was developed by Battelle, Pacific Northwest Laboratory (PNL) in the 1980s for remediation of soils contaminated with transuranic (TRU) material. The process utilizes electrical resistance heating to melt soil in place and fixes radioactive contamination by incorporation into a glass and crystalline waste form. Successful testing by PNL has proven the general feasibility and widespread applicability of the process.

To assess the applicability of ISV to buried waste, a comprehensive testing and analytical program has been developed. Testing is being done in a progressive fashion and includes both laboratory and field testing as well as evaluation of the vitrified products. Analytical modeling is being used to define the tests and predict results. In this way, ISV will be evaluated in comparison to other likely candidates for SDA remediation. The overall treatability investigation process is being guided by established EPA criteria.

Two INEL Intermediate Field Tests were conducted as part of the ISV treatability investigation and represented the first testing of the ISV process in buried waste. The tests were designed to provide data on overall process suitability, performance of equipment, and potential technical issues of concern. This report provides results of the INEL tests and is organized as follows. Section 1 provides background information on the SDA buried waste site, the ISV process, and the intermediate-scale ISV equipment. Section 2 outlines the test objectives and factors influencing the design of the tests. Information for Test 1 is presented in Section 3; this includes specific test objectives, details of test pit construction, and a detailed review and assessment of process data collected during the test. Similar information for Test 2 is provided in Section 4. Section 5 includes the observations and data collected during the posttest excavation of the two vitrified products, and results of product evaluation studies. Section 6 presents results of a study involving transport of tracer materials placed in the buried waste materials. A discussion of analytical modeling of hood transients is presented in Section 7. Conclusions are provided in Section 8.

1.1 Brief History of the Radioactive Waste Management Complex

The RWMC encompasses 144 acres in the southwest section of INEL, as shown in Figure 1. Formerly known as the Burial Ground, the SDA of the RWMC served as a disposal area for radioactive [intermediate- and low-level solid and liquid wastes and TRU and mixed-fission products] and nonradioactive

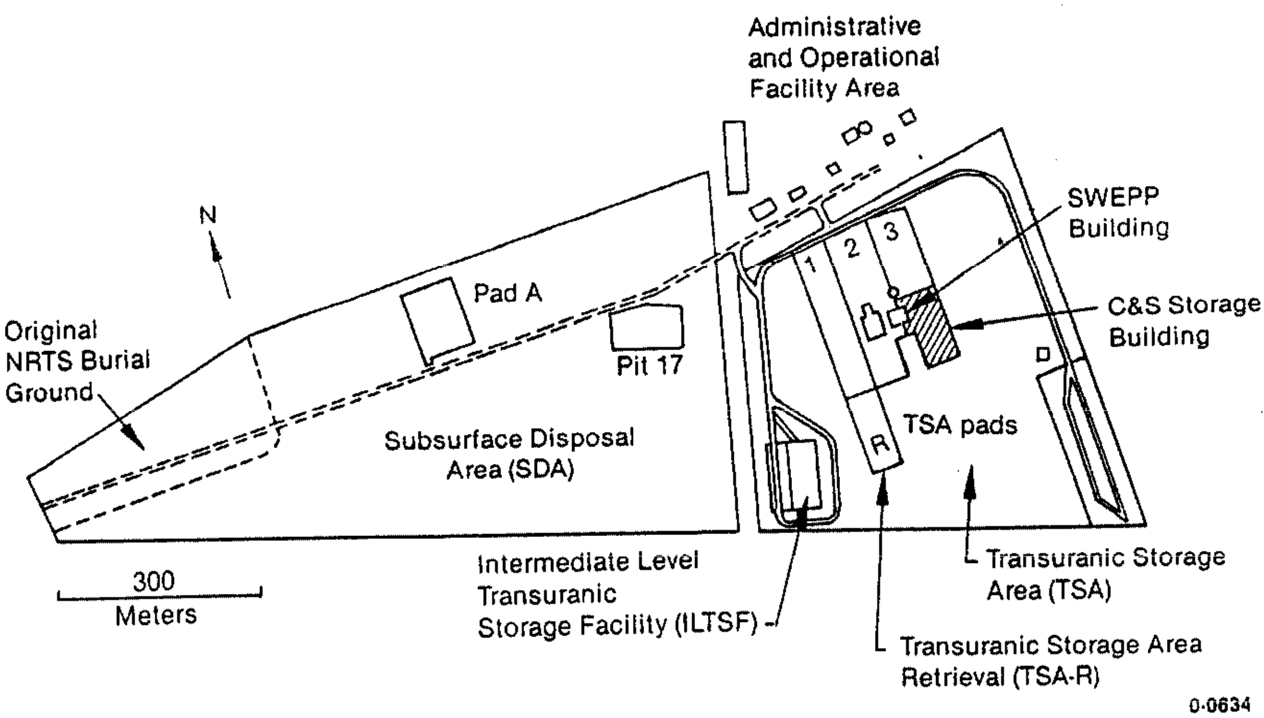

Figure 1. Radioactive Waste Management Complex.

hazardous wastes. The buried wastes were primarily generated by the DOE Rocky Flats Plant and INEL operations.

The SDA consists of belowground pits, trenches, and soil row vaults and one aboveground storage pad (Pad A). The pits are excavations that have surface areas of several acres and range in depth from 1.5 to 4.6 m (5 to 15 ft). In general, the pits were excavated to bedrock and covered with 0.61 m (2 ft) of soil, although some waste is believed to lay directly on basalt. Closure of a filled pit involved applying a final soil cover a few yards deep and planting stabilizing vegetation on the final cover.[1] Trenches at the SDA range in length from 30.5 to 305 m (100 to over 1000 ft) and were excavated approximately 1.5 m (5 ft) wide and an average of 3.7 m (12 ft) deep on 4.9 m (16 ft) centers. The waste was emplaced and usually, but not always, covered with at least 0.91 m (3 ft) of soil. The first trench at the Burial Grounds was opened for solid waste disposal on July 8, 1952. For about two years only mixed-fission product waste was buried. In April 1954 the first shipment of waste from the Rocky Flats Plant was received and buried in shallow pits and trenches with no segregation of TRU, mixed-fission product, and nonradioactive hazardous wastes. By 1957, ten trenches at the 13-acre site were nearly filled.

The site was then expanded to the 88-acre tract known today as the SDA. At that time, the use of large, open pits was initiated for the disposal of solid TRU wastes, with trenches reserved for the disposal of mixed-fission product wastes. Large, bulky items contaminated with mixed-fission product wastes were sometimes placed in the pits along with the TRU waste. During the 1960s, the SDA continued to receive TRU waste for disposal in the shallow land pits. Wastes in containers were deposited into the pits and trenches. Approximately 60% of the containers were steel drums (30 to 55-gal), 5% were plywood boxes, and 30% were cardboard and fiberboard containers.[1] Vehicles and large pieces of equipment were deposited without containers. From 1952 to 1963, the waste was stacked in the pits and trenches. From 1963 to 1969 the waste was randomly disposed into the pits to reduce worker exposure. This random placement continued until 1969, when stacking was reestablished. As a result, the distribution of wastes within the SDA is very heterogeneous, making the characterization of any portion of the pits and trenches difficult. Disposal of TRU wastes in shallow pits and trenches at the SDA ceased in 1970. During the SDA operational period of 1952 through 1970, approximately 118,000 m^3 (4.2 million ft^3) of waste were disposed.

1.2 ISV Process Description and Development Status

ISV is a thermal treatment that melts contaminated soils and wastes into a chemically inert glass or crystalline substance. The process is initiated by a square array of four graphite electrodes inserted a few inches into the ground, as shown in Figure 2. Because soil is not electrically conductive, a mixture of flaked graphite and glass frit is placed among the electrodes to serve as a starter path. Once an electrical potential is applied to the electrodes, an electrical current is started in the starter path beginning the melt. The graphite starter path is eventually consumed by oxidation, and the current is transferred to the molten soil, which is processed at temperatures between 1450 and 2000°C. As the molten or vitrified zone grows, it incorporates or encapsulates any radionuclides and nonvolatile hazardous elements, such as heavy metals, into the glass structure. The high temperature of the process destroys organic components by pyrolysis. The pyrolyzed by-products migrate to the surface of the vitrified zone and combust in the presence of air. A hood placed over the area being vitrified directs the gaseous effluent to an off-gas treatment system. The waste is then allowed to cool, trapping waste in the vitrified substance.

The successful results of 59 tests conducted under a variety of site conditions and with a variety of waste types have proven the general feasibility and widespread applications of the process.[2] Table 1 shows the different scales of testing units that PNL used in developing and adapting ISV technology. In addition, economic studies have indicated tremendous economies of scale are attainable with the ISV process.[3] ISV technology, refined to the point of being commercialized for specific types of contaminated soil sites has been broadly patented within the United States, Canada, Japan, Great

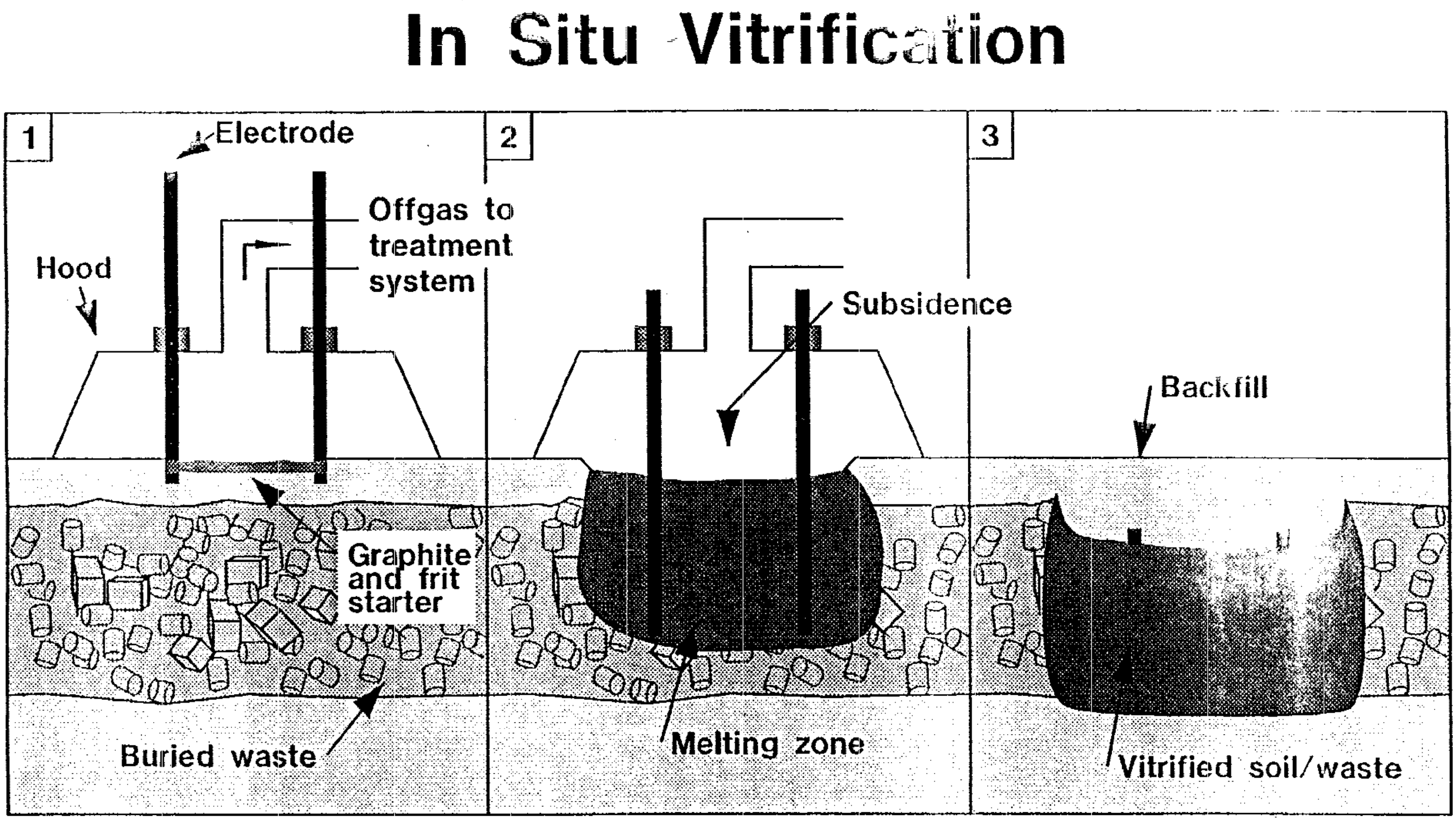

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Figure 2. Electrode insertion during the ISV process.

Table 1. Testing units for developing ISV technology

Equipment Size	Electrode Separation, m	Block Size	Number of Tests Completed as of 12/1/90
Bench-scale	0.11	1 to 10 kg	19
Engineering-scale	0.23 to 0.36	0.05 to 1.0 t	33
Intermediate-scale	0.9 to 1.5	10 to 50 t	20
Large-scale	3.5 to 5.5	400 to 900 t	6

Britain, and France. Current emphasis is on developing the technology for buried waste and other subsurface inclusions such as buried tanks.

1.3 Intermediate-Scale Test System

The intermediate-scale test system consists of four graphite electrodes, a power control unit, an off-gas containment hood over the test site, and an off-gas treatment system housed in a portable semi-trailer, as shown in Figure 3. A layout of the ISV equipment at a typical site is shown in Figure 4. Figure 5 shows the system setup at the INEL Test Site.

1.3.1 Power System Design

The intermediate-scale power system uses a Scott-Tee connection to transform a 3-phase input to a 2-phase secondary load on diagonally opposed electrodes in a square pattern with a single potentiometer controlling both secondary phases, as shown in Figure 6 The 500-kW power supply may be either voltage or current regulated. The alternating current primary is rated at 480 V, 600 A, 3-phase, and 60 Hz. This 3-phase input on the primary side feeds the Scott-Tee connected transformer, providing a 2-phase secondary side (the secondary phases are denoted as phase A and phase B). The transformer

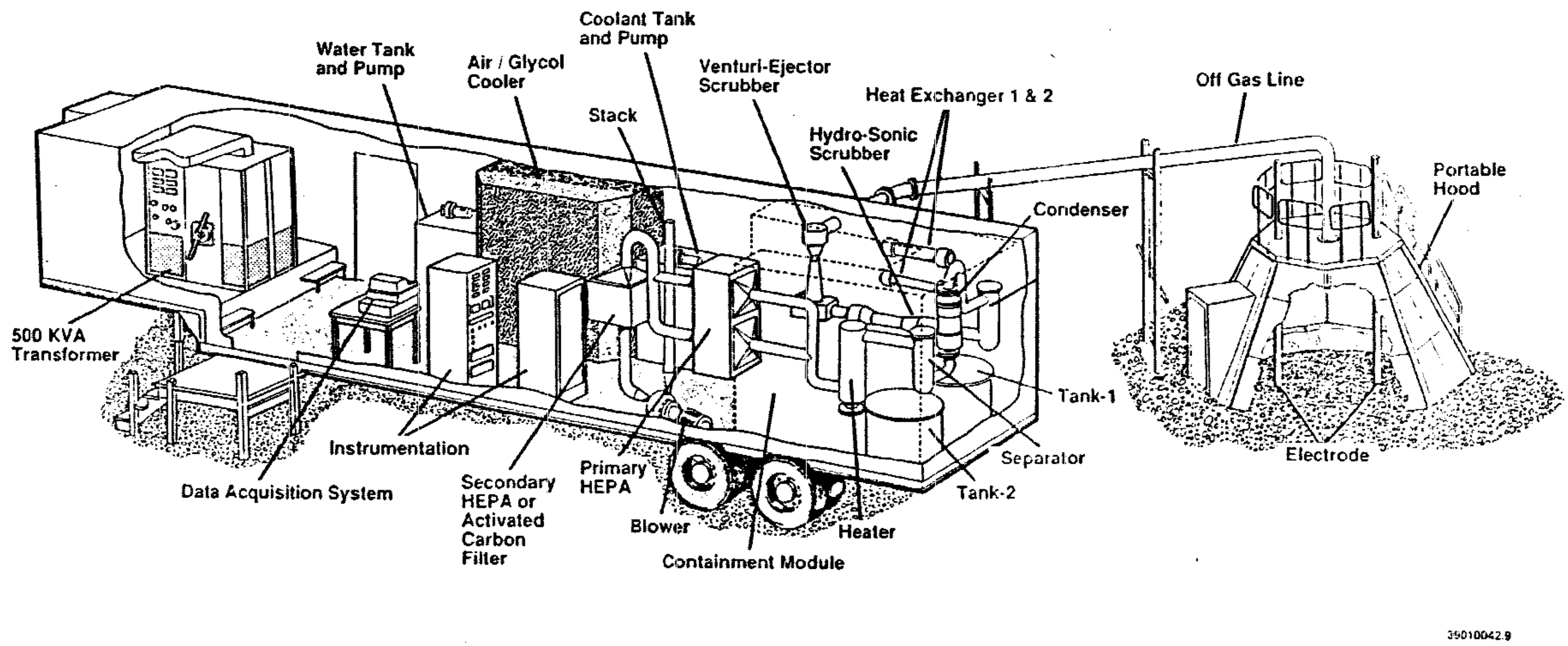

Figure 3. Cutaway view of the intermediate-scale process trailer and off-gas hood.

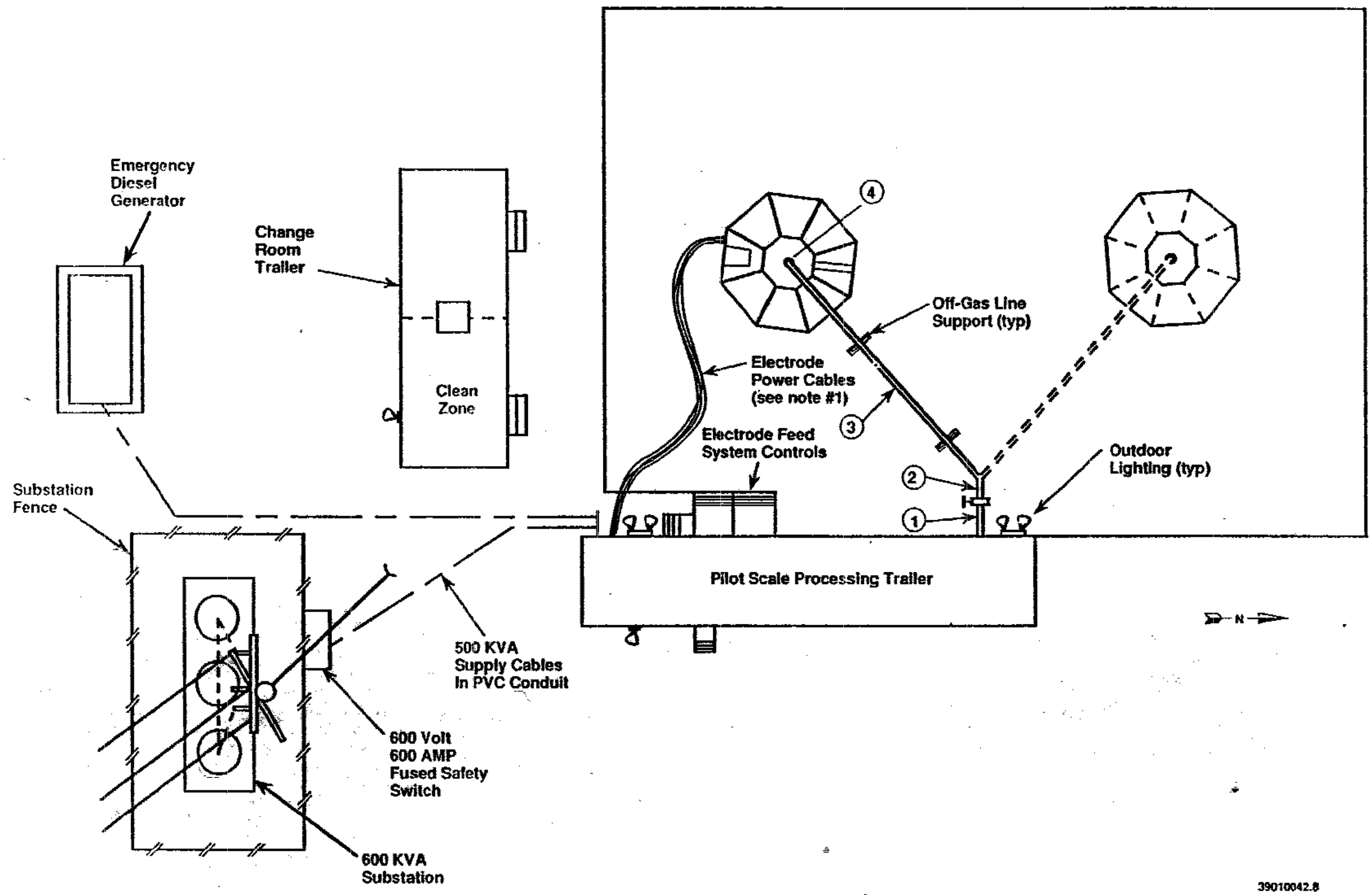

Figure 4. ISV equipment at a typical site.

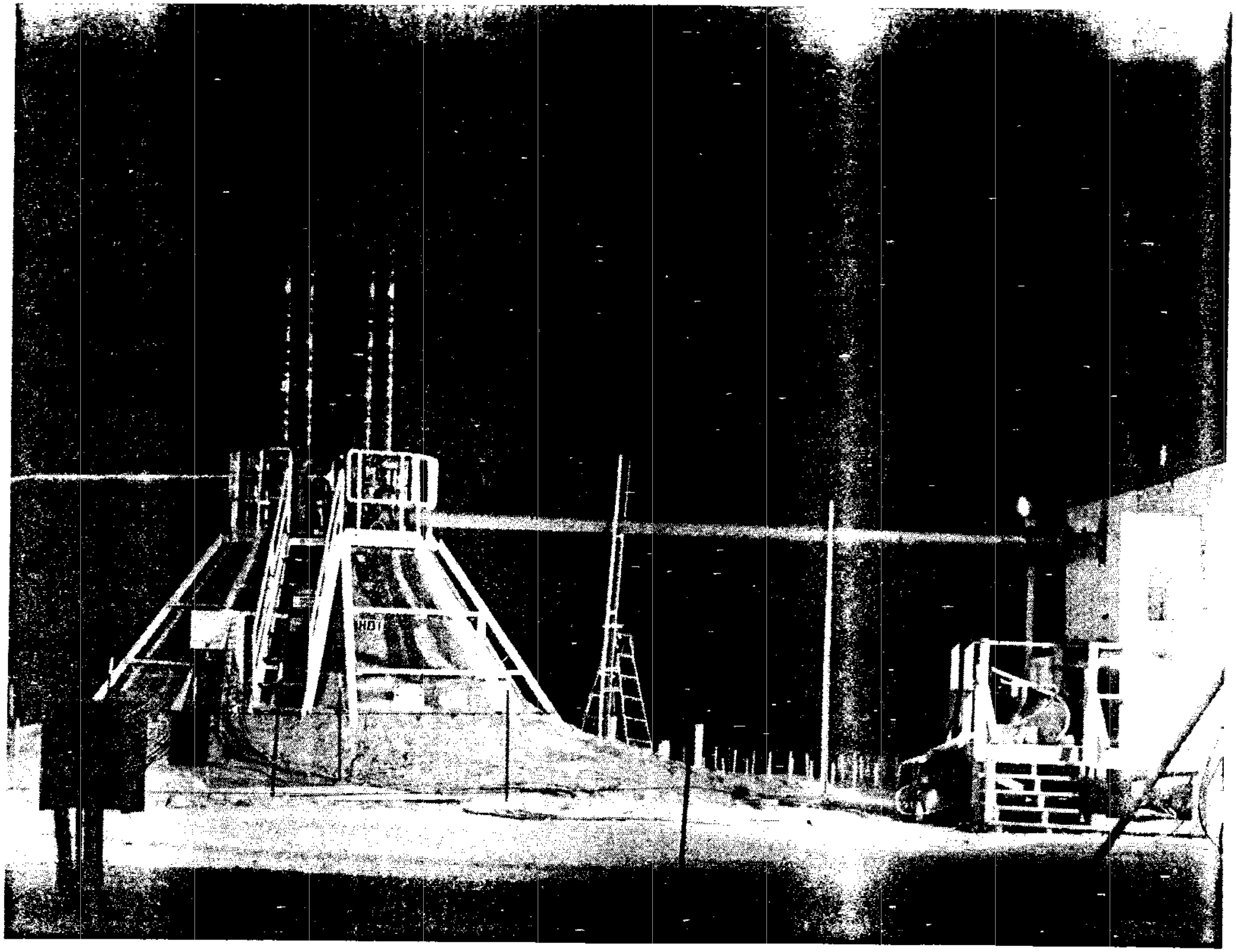

Figure 5. Intermediate-scale system setup at INEL Site.

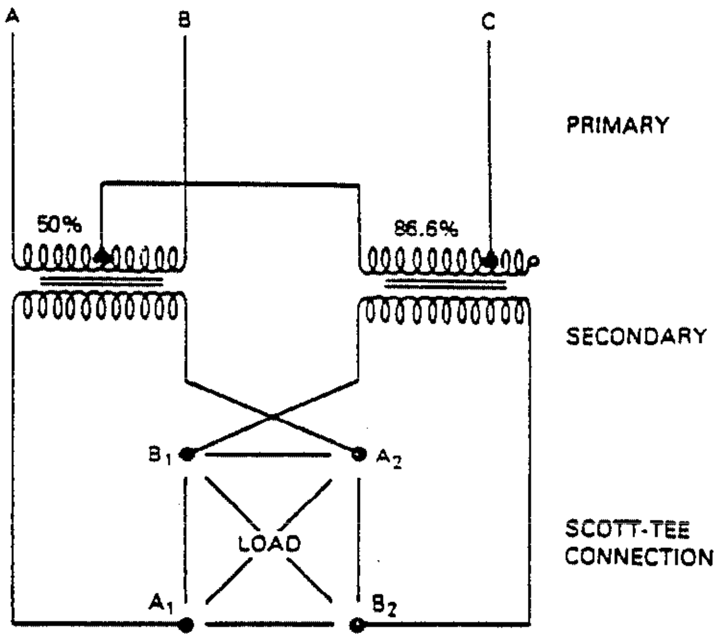

Figure 6. Scott-Tee electrical connection for the pilot scale ISV system.

has four separate voltage tap settings--1000 V, 650 V, 430 V, and 250 V. Each voltage tap has a corresponding amperage rating of 250 A, 385 A, 580 A, and 1000 A per phase, respectively. The amount of 3-phase input power delivered to the transformer is controlled by adjusting the conduction angle of the thyristor switches located in each of the three input lines. These switches, in conjunction with selectable taps on the transformer secondary, regulate the amount of output power delivered to both secondary phases. The Scott-Tee setup requires transformer taps at 50 and 86.6% of the primary transformer windings. The Scott-Tee connection provides an even power distribution when the molten zone approaches a uniform resistance load. The primary and secondary current is balanced for a Scott-Tee system when a balanced load exists.

1.3.2 Electrodes and Electrode Feed System

The graphite electrodes used to conduct current to the molten soil are 15.25 cm (6 in.) diameter and approximately 1.8 m (6 ft) long and are set up in a square array separated by a distance of 1.07 m (3.5 ft). Each electrode length is machined with female threads to allow connection of successive lengths via male threaded graphite connecting pins. The electrodes are initially buried to depths of 15 to 61 cm (6 to 24 in.), and the conductive mixture of starter path, consisting of graphite and glass frit, laid around and between the electrodes.

Electrodes are fed into the melt via a pneumatically controlled feed system. The electrode feed assemblies consist of four independently controlled, air-actuated systems with a feed system for each electrode. Each feed system has two air-actuated clamps and an air driven motor that provides vertical movement for one of the two air-actuated clamps. The moveable clamp allows the electrode to be inserted into or retracted from the melt. A second stationary clamp is provided to hold the electrode while the moveable electrode is being repositioned. Electrical contact from the power cables to each electrode is provided by a copper contact ring (brush), which is compressed to provide sufficient contact with the electrodes via a set of adjustable tension springs.

Normally, operations are conducted with the electrodes in a nongripped mode allowing the electrodes to rest on the bottom of the advancing melt front. As metallic objects, molten metal pools, or other electrically disruptive situations are encountered, the feed system is utilized to retract the affected electrode(s) until a stable electrical balance is achieved. Typically, a retraction of only 2 to 3 cm (1 to 2 in.) is needed to restore balance.

1.3.3 Starter Path

The starter path, consisting of a mixture of 35% glass frit and 65% graphite flake, is placed in a rectangular configuration with an electrode at each corner and a diagonal connecting the opposing electrodes. Preparations for laying the starter path involve ensuring the top soil of the area to be vitrified is free of coarse rock and other nonhomogeneous inclusions. The area is then covered with a 15 cm (6 in.) layer of sand. Next, a wooden form constructed of 2 x 4 in. studs cut to the length of the rectangular configuration is buried in the sand to the grade level and the area watered. Once the water has permeated the sand to at least the bottom of the studs, the studs are carefully removed leaving a trench with the approximate dimensions of 4 cm (1.5 in.) wide by 9 cm (3.5 in.) deep. In addition, hand-formed trenches of the same dimensions are formed around each of the four electrodes. At this point, a 2.5-cm (1 in.) deep layer of pure graphite flake is placed around the circumference of each electrode. Next, a 2.5 cm (1 in.) layer of the graphite/frit mixture is laid, and, finally, a 4 to 5 cm (1.5 to 2 in.) layer of the graphite/frit mixture is laid in the rectangular trench and also in the trenches of the diagonally opposing electrode pairs. Once the starter path is completed, it is covered with a 2.5 to 5 cm (1 to 2 in.) layer of fine soil or sand and is lightly patted in place. This layer of soil helps reduce the graphite particulate generation and carryover to the off-gas treatment system once powered operations are initiated.

Final preparations in the hood involve the placement of two layers of 1 in. thick KAO-WOOL insulation over the area to be vitrified. This silica insulation blanket is used to keep heat losses from the molten soil to a minimum, especially during the early stages of operations. During the latter stages of operations, after the melt has achieved greater depths, the heat losses are limited by the formation of the naturally occurring cold cap, which is a frozen layer of glass covering the molten zone.

1.3.4 Off-Gas Containment Hood

The off-gas containment hood is designed to collect off-gasses emanating from the melt and to direct them to an off-gas treatment system. Typical operating conditions in the hood range from 1 to 2 in. of water vacuum and 200 to 400°C. The hood is operated at the slight vacuum, which is created by an induced draft blower, and has a volume of approximately 28.3 m^3 (1000 ft^3) to provide a surge capacity that minimizes vacuum loss during periods of sudden gas release. With a flow of between 10 and 15 m^3/min, gasses in the hood have a residence time of approximately 2 minutes.

The hood is an octagonal pyramid positioned above the containment shell and provides a working platform for the electrode feed system, access for maintenance personnel during nonpowered periods of operation, and support for the containment shell, as shown in Figure 3 (see p. 8). Off-gasses collected in the hood are directed to the off-gas treatment system via a 20.3-cm (8-in.) diameter off-gas pipe. The complete off-gas hood assembly is highly portable and can be assembled for operation in less than 1 day. The containment hood is constructed from 304L stainless steel sheet metal, with the side panels constructed from 18 gauge sheet metal and the top constructed of 14 gauge sheet metal. The containment hood is fitted with a removable door for entry prior to and following the test. A viewing window to observe the melt during processing is included as an integral part of the door design. Electrodes penetrate through the roof of the hood down to the zone to be vitrified, with seals composed of three independent layers of KAO-TEX 1000 (a tight-weave high silica fabric suitable for use in high temperature applications) around each electrode. The electrode seal is created by a press fit of the 15.25-cm (6 in.) diameter electrode through a 14 cm (5.5 in.) diameter hole in each of the fabric layers. This fabric configuration provides a relatively tight seal around each electrode. The containment hood is sealed to the ground by piling soil around the base.

The hood design includes a seal pot assembly with a high-efficiency particulate air (HEPA) filter assembly. The seal pot assembly allows controlled air in-leakage into the hood for regulating vacuum and acts as a passive pressure relief system if the hood pressurizes from sudden gas releases. High pressure of approximately 1 in. of water causes a water seal to relieve and allows off-gases into the containment hood through the HEPA filter prior to venting the gases to the environment.

1.3.5 Off-Gas Treatment System

The off-gas passes through the off-gas treatment system, which consists of a Venturi-Ejector scrubber and separator, a Hydro-Sonic scrubber, a separator, a condenser, another separator, a heater, two stages of HEPA filtration, and a blower. The off-gas system is shown schematically in Figure 7. Liquid to the two wet scrubbers is supplied by two independent scrub recirculation tanks, each equipped with a pump and heat exchanger. The entire off-gas system has been installed in a 13.7-m long (45 ft) semi-trailer to facilitate transport to a waste site. Equipment layout within the trailer is illustrated in Figure 3 (see p. 8). All off-gas components except the final stage HEPA filter and blower are housed within a removable containment module. The containment module with gloved access for remote operations is maintained under a slight vacuum. This system was originally designed for testing radioactive-contaminated soil at the DOE Hanford Site.

The Venturi-Ejector scrubber serves as an off-gas quencher and as a high-energy scrubber. Heat is removed from the off-gas primarily via the Venturi-Ejector scrubber where aqueous scrubbing solution is sprayed into the off-gas stream. Heat removal from the scrub solution is accomplished by a closed loop cooling system, which consists of an air/liquid heat exchanger, a coolant storage tank, and a pump. A 50% water/ethylene glycol mix is pumped from the storage tank, through the shell side of the condenser, to the two

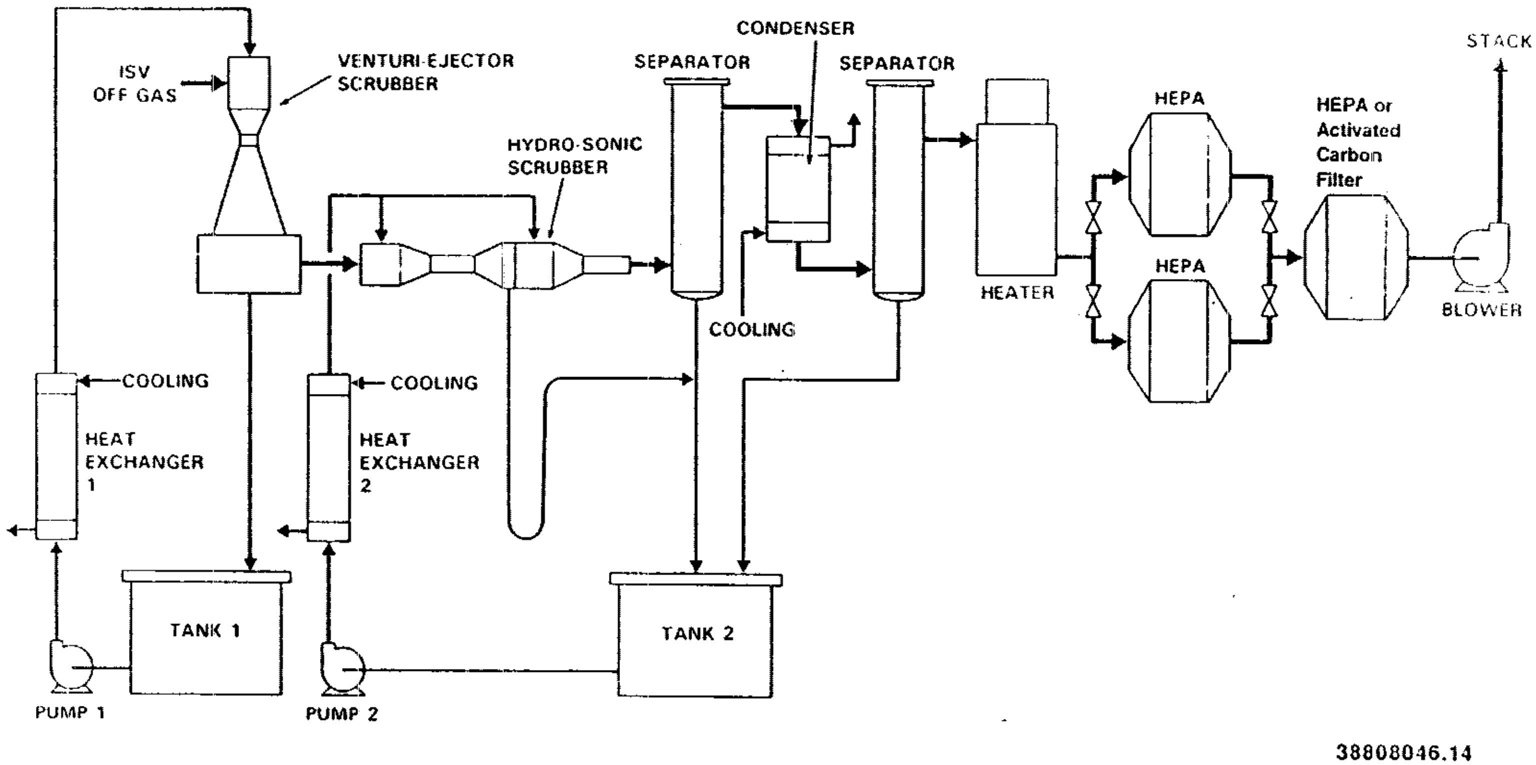

Figure 7. Schematic diagram of the intermediate scale ISV off-gas treatment system

scrub solution heat exchangers and then through the air/liquid exchanger where heat is removed from the coolant and discharged to the environment. The second scrubber is a two-stage Hydro-Sonic scrubber (tandem nozzle scrubber), as illustrated in Figure 8. The first stage condenses vapors, removes larger particles, and initiates growth of the finer particles so that they are more easily captured in the second stage. Particulate is captured when the gas is mixed with fine water droplets produced by spraying water into the exhaust of the subsonic nozzle. Mixing and droplet growth continue down the length of the mixing tube. Large droplets containing the particulate are then removed by a vane separator and drained back into the scrub tank. The unit is designed to remove over 90% of all particulate greater than 0.5 μ in diameter when operated at a differential pressure of 50 in. of water. Removal efficiency increases with an increase in pressure differential. Additional water is removed from the gas system by a condenser having a heat exchange area of 8.9 m^2 (96 ft^2) and a final separator. The gasses are then reheated ~25°C above the dew point in a 30-kW heater to prevent condensate in the HEPA filters.

The final components of the off-gas treatment system consist of two off-gas HEPA filters and an induced draft blower. The first stage of filtration consists of two 61 x 61 x 29-cm (24 x 24 x 11.5-in.) HEPA filters in parallel. During operation, one filter is used and the other remains as a backup in case the primary filter becomes loaded. The primary filter can be changed out during operation without process shutdown. The second-stage filter acts as a backup particulate filter in case a first-stage filter fails and is identical in construction and filtering efficiency as the initial-stage filters. The induced draft blower provides a total off-gas flow of between 10 to 20 m^3/min and creates a vacuum of approximately 100 in. of water.

1.3.6 Data Acquisition Systems

The Data Acquisition System (DAS) and associated instrumentation provide extensive process monitoring capabilities for ISV testing. For process control, inputs from process instruments are routed through a Hewlett Packard

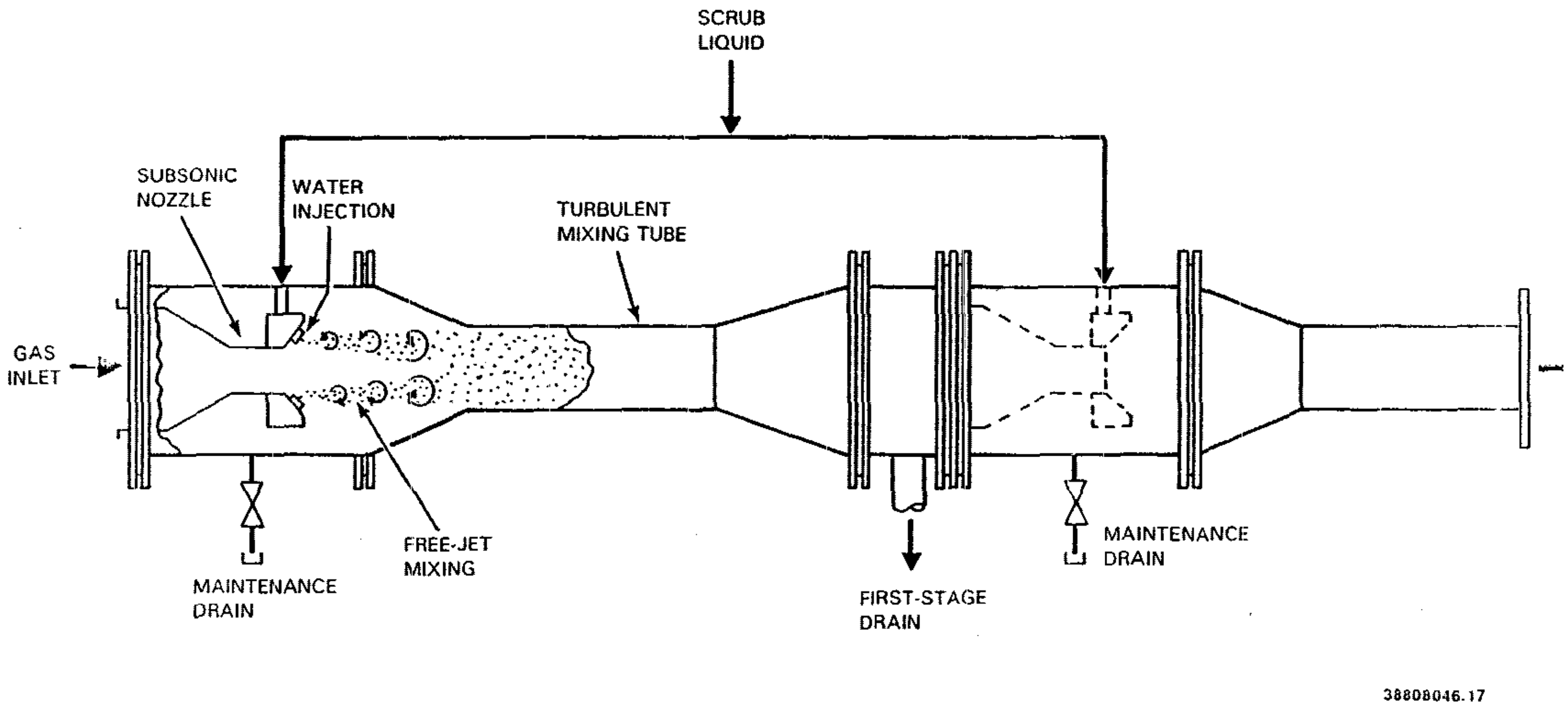

Figure 8. Tandem nozzle Hydo-Sonic Scrubber

model 3497A data acquisition and control unit linked to a MacIntosh II CX computer operating Lab View 2.0 software. The DAS scans, records, displays, and files process control informational data at the rate of twice per minute. The software allows essentially simultaneous manipulation of recorded data (for producing trend plots, etc.) while acquiring and storing data.

A second independent system, named the Priority Data (PD) system, scans, records, displays, and files critical process data at the rate of once per second. The PD system also features a visual alarm function to notify operators that operational limits (design parameters) have been reached. This system utilizes a second MacIntosh II CX computer operating Lab View 2.0 software to monitor the following eight data points associated with the off-gas containment hood.

- Two redundant hood vacuum points
- One plenum temperature
- One off-gas exit temperature
- Two wall temperatures (external and internal)
- Two roof temperatures (external and internal).

These eight parameters recorded by the PD system are sampled and stored at 1 second intervals; whereas the parameters recorded by the DAS are sampled and stored at 30 second intervals. As a result of this sampling frequency, the PD system provides better resolution of the maximum values of transient temperatures and pressures recorded in the hood. Inspection of the test data indicted the better resolution of the PD system was significant only in the recording of hood pressure transients because of the rapid spiking of pressure. In the case of pressure, the maximum value of pressure attained is more accurately recorded by the PD system. The rate of temperature change inside the hood was slow enough to be accurately resolved by either the DAS or the PD system.

The pressure transducers are Omega type transducers with a response time significantly better than 1 second. The range for the transducers is set to 5 in. of water vacuum to 5 in. of water pressure. The hood temperatures monitored by the PD system are acquired via 1/8-in. ungrounded stainless steel sheathed type K thermocouples.

2. TEST OBJECTIVES AND TEST DESIGN BACKGROUND

2.1 Test Objectives

Six major test objectives for the ISV Intermediate Scale Tests were identified.

- Verify the operational suitability of the electrode feed system (EFS)

- Verify acceptable vitrification in a region containing waste forms similar to those expected at the SDA

- Verify acceptable vitrification of a representative waste composition layer with minimum soil content

- Verify acceptable vitrification of a waste layer with high metal content

- Assess the potential for radionuclide transport during the vitrification process by using nonradioactive tracer materials

- Obtain engineering and scientific data necessary to assess the engineering capability of the ISV system, safety of the process streams, and suitability of the process as a remedial method.

Each of these objectives is justified as follows:

(a) Operational suitability of the EFS. All previous ISV tests have been conducted with the electrodes fixed at their maximum depth in the ground in predrilled holes. The EFS has been designed to allow the melt to be started with the electrodes inserted at depths of 15 to 61 cm (6 to 24 in.). As the melt progresses, the electrodes are fed down to their desired depth. This method of operation (no predrilling) is highly desirable to reduce contamination spread and exposure at radioactive sites. The suitability of the EFS will be demonstrated at the intermediate-scale before a full-scale EFS is designed and built.

(b) Verify vitrification in a region containing waste forms similar to those found in the SDA. It is necessary to demonstrate the suitability of the ISV technology in producing acceptable vitrified product from soil and waste forms like those found in the SDA. Where applicable, information from SDA Pit 9 was used as a representative; however, it is recognized that there is significant uncertainty and variability regarding waste composition throughout the SDA.

(c) Verify vitrification of a waste layer with minimum soil content. Stacked boxes and drums in areas of the SDA could result in waste layers with reduced amounts of soil. It is necessary to verify the technique will provide suitable vitrification in these situations.

(d) Verify acceptable vitrification of a waste layer with high metal content. Areas of high metal content can potentially result in the formation of a metallic pool layer with subsequent shorting of the electrodes. It is necessary to verify the suitability of the ISV/EFS technique under such circumstances because large metallic objects and areas of high metallic content may occur in the SDA.

(e) Assess the potential for radionuclide transport. The intermediate-scale tests present an opportunity to assess the behavior of radionuclides by using nonradioactive, nonhazardous simulants. Potential problems can be identified and addressed prior to full-scale testing in radioactively contaminated waste.

(f) Obtain engineering and scientific data necessary to assess the engineering capability of the ISV systems, safety of the process streams, and suitability of the process as a remedial method.

Because these tests were the first field tests of ISV for buried waste applications, they provided an opportunity to discover potential issues of concern. Additionally, they provided product samples for characterization efforts.

Because the primary purpose of the ISV process is to stabilize and immobilize nuclear and toxic waste components, the chemical morphology and release characteristics of ISV products must be known to provide an accurate performance assessment. The properties of ISV products are directly related to the composition of the waste and surrounding soil and the thermal history of materials reacted during vitrification and cooling. The application of the ISV process to buried waste and soil at INEL presents unique conditions compared to the homogeneous soil/waste conditions previously tested at Hanford and Oak Ridge National Laboratory. Because the INEL soil and buried waste differ from previous ISV tests of soil and waste, a detailed characterization of the INEL ISV products is required.

It is necessary to collect data that will allow assessment of the engineering, safety, and environmental acceptability of the ISV process when applied at the SDA. Of particular concern is the off-gas transients that may occur during the processing of buried combustibles. There is little data available for this application. The presence of nonhomogeneous waste such as that which exists at the SDA and the amounts of combustible waste require a solid understanding of vitrification of different waste forms and gas releases from the melt be obtained. In addition, the engineering data obtained may be used to define design requirements for future testing or production systems.

2.2 TEST DESIGN INFORMATION

Two Intermediate Field Test pits were designed to meet test objectives described in Section 2.1. The first test was designed primarily to assess the performance of ISV in a region of randomly disposed waste. The second test was designed to assess performance in regions of stacked drums and in regions containing high-metal content wastes. A number of issues influenced the design of both tests and are described below.

2.2.1 Radionuclides and Hazardous Chemicals

Because the major objectives of the ISV Intermediate Field Tests were related to overall assessment of the ISV process on buried waste, radionuclides and hazardous chemicals were excluded. The exclusion of radionuclides was expected to have little effect on vitrification process parameters. The overall process behavior would be expected to be similar whether or not radionuclides were present. However, the exclusion of volatile organic materials was recognized to be a compromise in that vitrification parameters may be different in areas of the SDA where organic materials are present. Data collected as part of the ISV laboratory testing program will be used to assess potential areas of difference. Measurements of organic migration will be conducted in controlled conditions during laboratory testing.

2.2.2 Scaling Issues

The tests were conducted using PNL intermediate-scale equipment that mandated the test pits be scaled allowing test data to assess the expected performance of a large scale system at the SDA. PNL provided computer derived recommendations for electrode spacing for both the intermediate scale and large scale ISV systems. A 3.51-m (11.5-ft) distance between the large scale electrodes was recommended for a 6.10 m (20 ft) melt depth of INEL soil. The recommended intermediate scale value for electrode spacing was 1.07 m (3.5 ft) and was scaled from the large scale spacing to provide equal power density (kW/m^2) to the melt at each scale. The intermediate scale ISV system has a reduced power output relative to the large scale system.

The waste containers used in the intermediate-scale test were scaled representations of 55-gal drums and 1.2 x 1.2 x 2.4 m (4 x 4 x 8 ft) boxes. The linear dimensions were reduced by the ratio of the electrode spacing (3.5/11.5), therefore reducing the volume of waste containers by $(3.5/11.5)^3$. Standard containers with volumes closely approximating the calculated scaled volumes were used.

2.2.3 Waste Fractions and Disposal Efficiency

The intermediate-scale test pits were designed to include waste fractions similar to those found in the SDA.[4] Significant uncertainties exist regarding the distribution of waste throughout the SDA. The solid radioactive waste stored at the SDA is mixed with nonhazardous waste including broken equipment, lumber, paper, rags, plastic, and other solid debris. In addition, substantial amounts of organic waste from the Rocky Flats Plant exist in several pits. The test pit waste fractions for drums and boxes are found in Table 2. Separate waste materials were not mixed within individual drums (i.e., 50% of the drums consisted of entirely combustibles, 30% of entirely sludge, etc.).

Table 2. Volume of waste fractions

Container	Contents	Waste Fraction
Drums:		
	Sludge	0.30
	Combustibles	0.50
	Metals	0.08
	Concrete/glass	0.10
	Wood	0.02
Boxes:		
	Metal	0.80
	Concrete/glass/ wood	0.20

In addition, significant amounts of organic wastes contained in 55-gal drums from the Rocky Flats Plant are buried in Pits 5, 6, 9, and 10. Much of the sludge buried in Pit 9 consists of Organic Setups, Content Code 3, which was produced from treatment of liquid organic wastes generated by various plutonium and nonplutonium operations at Rocky Flats Plant.[5]

An important parameter of concern for the ISV process is the disposal efficiency ratio: waste volume/total volume. The same information can also be [illegible] in terms of soil-to-waste ratio. The relative amount of soil and waste is important for vitrification in order to produce a durable product and to ensure suitable amounts of soil to maintain conductance to the melt during the process. The soil-to-waste ratio limitations have not been defined for the ISV technology; therefore, the performance of the ISV process under

SDA-representative disposal efficiencies needs to be assessed. For Pit 9, a reasonable estimate of disposal efficiency is 0.25;[a] however, this is an average value for the entire pit. In local areas such as a stacked drum or box region, the disposal efficiency can be significantly higher.

2.2.4 Waste Materials Composition

The materials used in preparing the pit waste included steel drums and cardboard boxes. The 55-gal drums were simulated with carbon steel containers manufactured by Central Can Company of Chicago, Illinois. The containers were approximately 9.5 L (2.5 gal) capacity and 0.79 kg (1.75 lb). A lid was provided for each container and could be crimped to contain the waste; however, no effort was made to seal the cans. The boxes were simulated with standard cardboard boxes manufactured by Tharco Company of Salt Lake City, Utah. For structural strength, each box consisted of two boxes: an inner and outer box. The inner box measured 76 x 46 x 41 cm (30 x 18 x 16 in.), and the outer box measured 77 x 47 x 47 cm (30.5 x 18.5 x 18.5 in.). The combined weight of the boxes was 3.6 kg (8 lb).

The waste materials placed into the containers consisted of simulated sludge, combustibles, concrete/glass, metal, and wood. The combustibles consisted of computer paper and fabric used for combat fatigues. The concrete was obtained from a scrap pile 200-300 yards southeast of the INEL Water Reactor Research Test Facility (WRRTF) and was verified to be free of radioactive material by Test Area North (TAN) Health Physics. The glass was purchased from American Recycling in Idaho Falls, Idaho. Wood used as waste material was obtained from INEL cold waste dumpsters. The metal waste consisted of carbon steel and stainless steel from scrap piles on-site and at Pacific Steel. Much of the scrap carbon steel was rusted. Additionally, the carbon steel cans used to contain the waste were exposed to the weather prior to being placed in the pits and were rusted as well. It should be noted that previous retrieval projects at the SDA have resulted in the retrieval of badly deteriorated drums.[6,7] Most likely the containers used for the ISV

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a. Engineering Design File, BWP-ISV-011

Intermediate Field Tests, even though slightly rusted, are in as good or better shape than most 55-gal drums likely to be found at the SDA.

Sludge was simulated by mixing 1.05 kg (2.31 lb) of MICRO-CEL E, 0.32 kg (0.70 lb) of FLOOR DRI, and 3.50 kg (7.71 lb) of water. MICRO-CEL E is the main ingredient used for solidification of Content Code 3 sludge. FLOOR-DRI is a dried clay material that simulates the clay material used in preparation of Rocky Flats Plant sludge. Table 3 provides a typical analysis of MICRO-CEL E and FLOOR-DRI. Hazardous organic materials were not added to the test pits; instead, the test pit sludge materials consisted of absorbent materials minus the organic materials. Water was substituted for the organic volume in order to provide a more realistic amount of vapor release into the off-gas system.

2.2.5 Test Pit Soil Material

The ISV test pits were built near the WRRTF at TAN, approximately 27 mi. northeast of the RWMC, as shown in Figure 9. In order to minimize the potential for processing difference resulting from different soil types found at the SDA and WRRTF, soil from the SDA lakebed (located near the RWMC but not part of the SDA area) was used for backfilling the ISV test pits. Soil from the lakebed was typically used as backfill soil within the SDA when additional soil was needed (e.g., to fill in subsided areas in the overburden or to supply additional overburden soil). Table 4 shows an analysis of the mineral constituents of the SDA lakebed soil.

2.2.6 Selection of Tracer Materials

Both test pits contained rare-earth tracers used to simulate the presence of plutonium. Test Pit 1 was spiked with three tracers: dysprosium oxide, ytterbium oxide, and terbium oxide. Test Pit 2 was spiked with dysprosium oxide. Detail on the Tracer placement and objectives of the Tracer is presented in Sections 6.3 and 6.4.

Table 3. Chemical composition of sludge

Element	Weight Percent
MICRO-CEL E[a]	
SiO_2	56.0
Al_2O_3	3.8
Fe_2O_3	1.0
CaO	26.0
MgO	0.7
Na_2O	0.6
K_2O	0.6
LOI[b]	11.3
FLOOR DRI[c]	
SiO_2	89.2
Al_2O_3	4.0
Fe_2O_3	1.5
CaO	0.5
MgO	0.3
Na_2O	0.25
K_2O	0.25
H_2O	4.0

a. The data for MICRO-CEL E were obtained from the manufacturer: Manville Corporation, Filtration and Minerals Division, Denver, Colorado 80217-5108 (303) 978-2000.

b. The loss on ignition (LOI) is assumed to include water and other nonhazardous volative materials.

c. The data for FLOOR DRI were obtained from Mr. Pat Flynn of Eagle-Picher, Reno, Nevada 89510, (702) 322-3331.

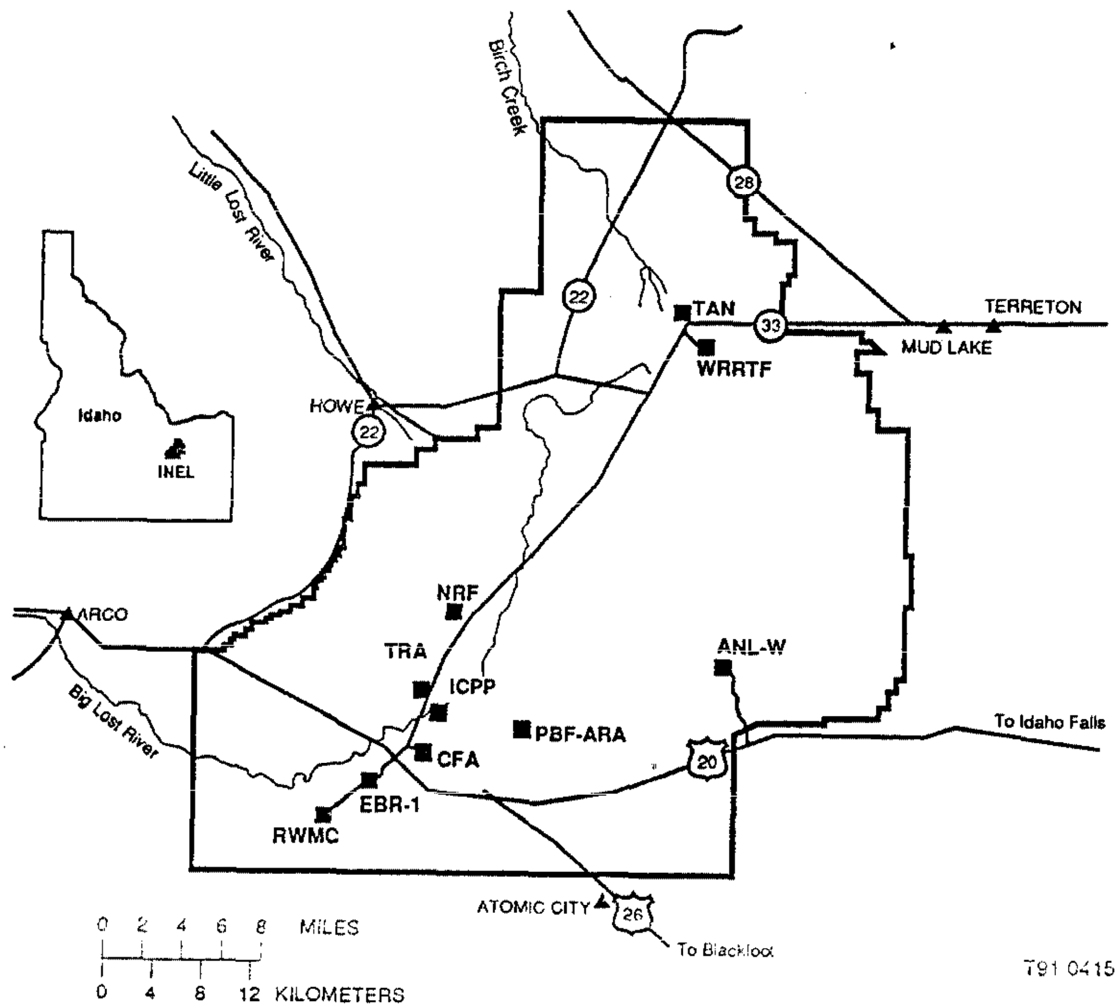

Figure 9. Map of INEL showing the WRRTF where the Intermediate-Scale Test took place.

Table 4. Chemical composition of SDA lakebed soil[a]

Element		Weight Percent
Silicon Oxide (SiO_2)		62.60
Aluminum Oxide (Al_2O_3)		11.85
Iron Oxide (Fe_2O_3)		4.25
Calcium Oxide (CaO)		3.68
Potassium Oxide (K_2O)		2.99
Magnesium Oxide (MgO)		1.72
Sodium Oxide (Na_2O)		1.37
Titanium Oxide (TiO_2)		0.68
Manganese Oxide (MnO_2)		0.10
Barium Oxide (BaO)		0.09
Zirconium Oxide (ZrO_2)		0.05
Boron Oxide (B_2O_3)		0.05
Nickel Oxide (NiO)		0.04
Strontium Oxide (SrO)		0.02
Chromium Oxide (Cr_2O_3)		0.02
	Total Oxide	89.5
	Water (H_2O)	7.50

a. Intermediate-Scale Testing of In Situ Vitrification, IS-INEL Test Plan, Rev. 1, Pacific Northwest Laboratories, March 1990.

2.3 Test Pit Construction Background Information

Two test pits were constructed for the ISV Intermediate Field Tests. In March 1989 a previously disturbed area (old baseball diamond) near the WRRTF was chosen for construction of the test pits. This area was chosen primarily because of the relative ease of supplying the required power. An environmental evaluation was performed prior to fieldwork activities. In May 1989 four holes were augured in the ground at the test site to verify that there was sufficient topsoil for construction of the test pits. In the area of the test pit there was 3.65 to 5.18 m (12 to 17 ft) of soil above basalt, with the topsoil at the western-most hole being 3.65 m (12 ft). Prior to test pit excavation, the test area was surveyed and staked, allowing correct placement of the two test pits relative to the position of the off-gas and administrative trailers. Construction of the test pits began on August 23, 1989. Test Pit 1 was filled on September 1-2, and Test Pit 2 was filled on

September 7-8. During pit digging and filling the weather was sunny and dry. After filling, the test pits were left undisturbed. No subsidence of the soil in the test pits was observed prior to the initial test operations in October 1989.

The waste containers for the test were filled in June - July 1989. After filling they were stored inside the WRRTF fence until the test pits were ready to be filled. The boxes were stored inside to protect them from the weather, and the cans were stored outside stacked on pallets. Rusting occurred on the exposed cans.